ADVANCED METHODS FOR ASTRONAUT TRAINING

Computer Based Training and Virtual Reality Technology

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Abstract. An overview of the critical aspects and the applicable training methods, related to the astronaut preparation for the missions to the International Space Station (ISS), is presented. Computer Based Training (CBT), an advanced method to be used by the space station astronaut trainees, is discussed: emphasis is laid to the development of the CBT lesson "Columbus Orbital Facility General Overview". That is the first lesson produced by the European Astronaut Centre, Cologne, about the Columbus Orbital Facility (COF).
A presentation and critical analysis of the Virtual Reality technology, as possible candidate for astronaut training, is supported by an evaluation, trough a purposely designed test application (the VETAT test), of a Virtual Reality system with force feedback, developed by PERCRO laboratory of Scuola Superiore Sant'Anna, Pisa.

Key words: Astronaut Training, Computer Based Training, Virtual Reality , force feedback, International Space Station

1. INTRODUCTION

Astronaut training is the development of required knowledge, skills and attitude to perform the overall crew operations during space missions, i.e. the systems and payload activities. Particularities of the missions to the International Space Station (ISS) require the application of new astronaut training principles. Precisely the international character of the crew-members, the long duration missions, the complexity of the station, the payload changing on-orbit over the lifetime of the station, are some of the new challenges that have to be envisaged and considered during the training development and delivering process. In that scenario the selection of the instructional methods is a very critical aspect.

The International Training Control Board (ITCB) is the administrative body, having the responsibilities of establishing training standard and procedures for the International Space Station. On the basis of the ITCB standards the following methods, beyond Computer Based Training, are to be used for the training of astronauts to ISS missions: classroom instruction, training manuals, study guides and video based instruction, being especially suitable for knowledge and familiarisation, will be mainly used for the basic and advanced training phases; part task simulators, paper sim training and, finally, full simulators, especially suitable for skills and attitudes acquisition, will be mainly used for mission training [Ref.6].

2. COMPUTER BASED TRAINING FOR THE INTERNATIONAL SPACE STATION

Computer Based Training (CBT) is computer delivered training, organized in multimedia lessons combining text, static graphics, animation, audio, and video and simulations to teach the learner concepts, procedures, recognition and problem resolution. CBT is a self paced medium, which is able to give effective training at three pedagogical level: knowledge and familiarisation, skills acquisition and operations (servicing and maintenance) capability. The key concept of such a method is the interactivity between the trainee and the personal computer [Ref.5]. In term of pedagogical effectiveness, the CBT method preserves the features of "Classical methods" as classroom instruction, training manuals, study guides and video based instruction, but Computer Based Training gives some other critical advantages. The most important of those is its portability, particularly interesting for the application in the astronaut training for the International Space Station: CBT medium allows the so called "remote training". That decreases dependence of special training sites, making the CBT a really cost-effective method, in spite of its high development costs [Ref.1]. In fact the main weakness of CBT is the very high development cost [Ref.3].

2.1. The CBT lesson "Columbus Orbital Facility General Overview"

The European Space Agency, as ISS partner, will have to provide Basic Training to its astronauts, and Advanced and Mission Training to all ISS astronauts on its elements and payloads; the CBT lesson "Columbus Orbital Facility General Overview", is the first Computer Based Training lesson produced for that purpose. In effect the main task of the development of this astronaut training lesson has been to build a prototype CBT lesson, that was a test bed to evaluate the potentiality of the medium, pointing out its values and defects, and to enable experience to be gained in its suitability for ISS crew training, knowledge attainment and standards adoption [Ref.2]. The "COF General Overview" is a lesson for knowledge and familiarization purposes, referring to the Columbus Orbital Facility (COF), the European laboratory module of the International Space Station; that is a general-purpose laboratory which can be reconfigured on orbit, trough the exchange of standard racks with scientific and functional equipment [Ref.1].
The development of this CBT involved: one Curriculum Developer (having the main task of ensuring pedagogical effectiveness to the lesson), two Subject Matter Experts (taking care of the technical contents) and one Lesson Author (taking care of software implementation). The development of the "COF General Overview", required four main steps:

- First a task analysis was carried out, in order to derive training objectives;

- Then, the Curriculum Developer and Subject Matter Experts derived from the objectives the lesson organization and strategy;

- A subsequent phase was the production of the Functional Flow Diagram, which reports on a single leaf the overall structure of the lesson, and of the Text Scenario and Graphic Scenario, delineating the details of each page of the lesson and containing the effective items to be inserted within (Figure 1 shows the high level Flow Diagram of the lesson);

- Last phase was the development of the software version of the lesson, using a program for multimedia productions (Authorware).

The above described procedure gives idea of the complexity of CBT lesson development and the need of standardization. The final product was recorded on CD-ROM (Figure 2 shows one sample page of the lesson) and delivered to European Astronauts in June 1997. From year 2000 the "Columbus Orbital Facility General Overview" CBT lesson will be used for training the astronauts for the International Space Station missions.

3. VIRTUAL REALITY SYSTEM FOR ASTRONAUT TRAINING PURPOSE

Alternative and less usual training method is Virtual Reality, a medium that provides participative three dimensional visualization and simulation of computer generated worlds [Ref.8].
The task achievable in the astronaut training field using VR immersive system might be the same of that achieved with simulators: to be able to provide accessible, safe and yet entirely realistic training environment. Moreover Virtual Reality systems offer advantages in safety (there cannot be any possible damage to 'real' equipment or processes if or when mistakes are made by the trainees), flexibility (with the same hardware architecture it is possible to simulate different scenarios, to have different simulators in one) and capability to be employed for uses other than training (e.g. for quick prototyping of different configurations). Main weaknesses of the immersive VR techniques are the high costs of the hardware and the software to have high performance systems and the possibility of inducing "simulation sickness".
Until present day Virtual Reality method has been just extensively used once in space training, for the Hubble Space Telescope servicing mission (STS 61) in 1993 [Ref.9]. In that NASA application of VR the grasping and the real dynamic behaviour of the objects were not simulated, and neither was the force feedback.

3.1. The VETAT test

Those strong limitations to the simulation realism are overtaken by an experimental application of a Virtual Reality force feedback system, called VETAT test (Virtual Environment Technology for Astronaut Training). The purpose of the VETAT test was to assess the readiness level of the Virtual Reality advanced technology for astronaut training aim. The VETAT test has been conducted on the advanced Virtual reality set-up called VETIR (VR Environment technology in Rehabilitation) developed by the PERCRO laboratory of the Scuola Superiore Sant'Anna, Pisa Italy. The items of VETIR set-up, that were used for the VETAT test, are [Ref.4]:

- *The External Force Feedback (EFF) arm* [Fig.3]: a right arm exoskeleton performing two functions:
    - To measure the user's arm motion: i.e. to follow and record the configuration of the operator's arm during manipulative task and gestures procedures.
    - to apply forces to the user's arm, replicating the external forces acting on the hand and on the arm, as required by the simulation.

  The EFF system consists of five Degrees of Freedom exoskeleton, made by light aluminium alloy,wrapping up the whole arm, sensorized with rotation sensor and actuatorized with DC motors.
- *The Sensorized Glove* [Fig.3]: a glove-like interface, mechanically connected to the EFF, able to read the fingers positions and orientations for all the 20 degrees of freedom of the hand. It has to be stressed that the glove does not provide any force feedback.
- *The VETIR Software Architecture* : implementing the virtual environment and controlling the interfaces. The main algorithms used for the second aim are three:
    - the collision detection module, that gives the contact plane and the interpenetration depth for the collisions between two objects or between the operator's arm and one object;
    - the force module working out the interaction forces (using the so called spring methods);
    - the dynamics module, making the integration of the rigid body dynamics equations.

3.2. The virtual space operation

The VETAT test application consisted on simple simulations of an operation to be carried out in a virtual microgravity environment. This exercise was thought as a sample of an astronaut training simulation session in preparation to a specific IVA or EVA mission, and, in particular, consisted in grasping a virtual object in a space module, removing it from its initial location and bringing it to a final site. A virtual microgravity environment was set up: since it was simulated the lack of gravity, the only acting forces were the inertial ones and those due to the collisions and contacts: so, for example, if the operator-trainee after having grasped the object opened his hand and released it, the object went away, with the set linear and angular velocity, moving and rotating like in the real space. The scenario designed to set the simulation was a stylised representation of the Columbus Orbital Facility interior, 4 meters long and 2 meters large and high. One of the lateral walls of the drawn module had thickness larger than the other ones, so making that wall active, from the point of view of the collision detection [Ref.1]. In that wall there were two slots, perpendicular one to each other, located either at the interior or at the exterior, to simulate the same procedure, later on described, as Intra Vehicular Activities or Extra Vehicular Activities. The virtual object to be grasped was a box with a handle, 20 centimetre long and 10 centimetre large, representing a payload experiment sample or an Orbital Replaceable Unit. The Figure 4 shows a screen-shot taken during the test execution in the EVA virtual environment (at the exterior of the COF model): the arm and hand of the user, wearing the EFF and the Sensorized Glove, are reproduced within the virtual scene.
At the beginning of the test the object was inserted in the "vertical" slot in the wall of the space module: task of the training session was to grasp the object, to extract it from the first slot and to bring it into the other slot. The active elements of the scene, from the point of view of the collision detection, were, beyond the arm and the hand, the object and the wall around the two slots. The arrows, appearing in the Figure, represent the vectors of forces acting on the user's hand palm and fingers phalanxes, due to the grasping of the object.

The feedback force on the fingers, due to the grasping internal forces, is only visual, because the Sensorized Glove can only read the position of fingers. But if the user, during the simulation, hits the virtual wall with the hand or with the grasped object, he perceives the corresponding external forces, on the hand metacarpus.

3.3. Results Analysis

The activity simulated was deliberately chosen extremely simple, as well as the virtual scenario, constituted by few tens of graphic polygons, being the main task of the application to assess the system and point out its potentiality. Of course, in a real application for astronaut training, great attention should be paid to the realism of the perceived scene.

The main weakness of the system, it demonstrated to be the delay of the responses, especially during the collisions, when the amount of calculations to be performed in real-time greatly increases. So the frame rate, which was acceptably high during the "free motion" (30-32 frames par second), was falling to less than 10 frames par second when collisions were detected: that makes the movement intermittent and spoils the realism of the simulation. In spite of those surmountable problems, the VETAT test application already presents an important improvement respect to the NASA Virtual Reality training application, above described, because of the simulation of collisions and grasping, dynamic behaviour of the objects and force feedback.

Possible developments of the PERCRO system for application to astronaut training purposes are:

- To provide the user with a navigation capability within the virtual environment (at present, the user's shoulder position is fixed in the scene).
- To replicate, using the EFF arm exoskeleton, the torques needed to actuate the joints of the EVA spacesuit sleeve, that is modeling also the interaction astronaut-spacesuit.
- To simulate the encumbrance of the spacesuit by changing the graphic representation of the arm in the virtual scenario.

4. CONCLUSIONS

The portability is the main advantage of Computer Based training, making it a cost-effective method for the training of the International Space Station astronauts, in spite of its high development costs. The main task of the development of the Computer Based Training Lesson "COF General Overview" in collaboration with the European Astronaut Centre, was to gain experience on CBT, building a prototype lesson, that was a test bed to evaluate the potentiality of the CBT medium and to fix guidelines and standards for the production of the other Computer Based Training lessons, in the framework of the ESA Advanced and Mission Training programme for the astronauts of the International Space Station. The acquired experience will make considerably easier, quicker and, therefore, more cost-effective the development of the other ESA CBT lessons.

Virtual Reality training has the potential to improve current ground training of astronaut IVA and EVA operations using low gravity simulations for the continuous and intensive on-orbit operations supported by the Station training programme. The VETAT test application of the PERCRO's Virtual Reality system demonstrated the potentiality of the immersive VR systems, as possible astronaut training method complementing the existing ones (particularly CBT): certainly it is also highlighted that some development problems are still to be solved, first of all the present-day mechanical hardware limitations, as regard as the interfaces user-machine.

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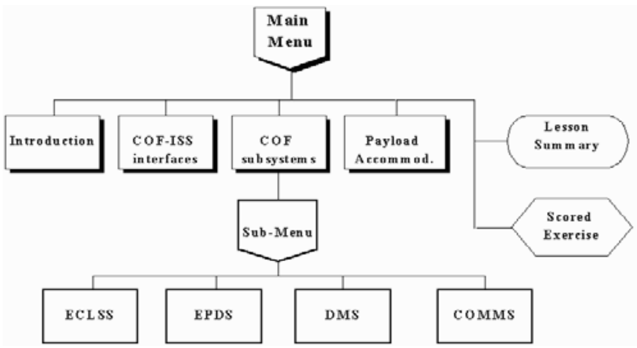

Figure 1. High level flow diagram of the Computer Based Training lesson *"Columbus Orbital Facility General Overview."*

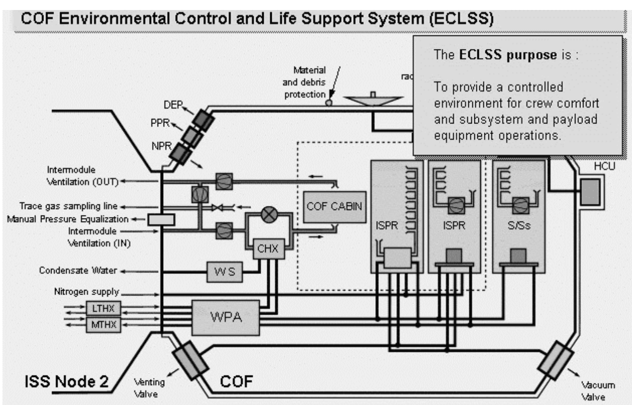

Figure 2. Sample page of the CBT lesson *"Columbus Orbital Facility General Overview."*

Figure 3. User wearing the External Force Feedback arm, the Sensorized Glove and the Head Mounted Display during the execution of the VETAT experiment.

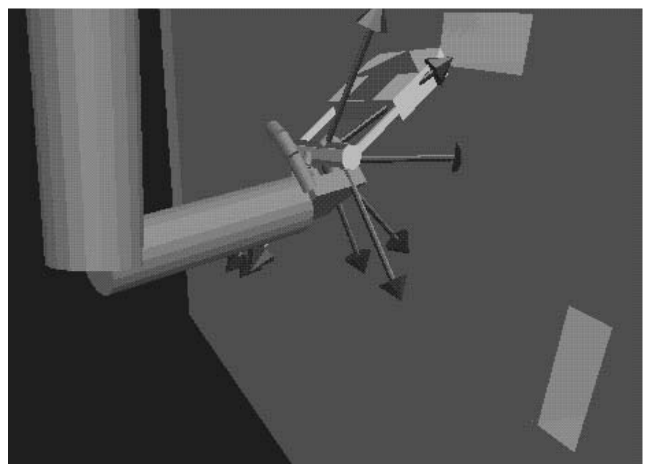

Figure 4. Screen-shot taken during the VETAT test execution in the EVA virtual environment.